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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 1-88

THERMAL CONSIDERATIONS WHEN USING THE MK 16 Mod 0  
UNDERWATER BREATHING APPARATUS IN 4.4°C (40°F) WATER

LCDR M. E. KNAFELC, MC, USN

FEBRUARY 1988

NAVY EXPERIMENTAL DIVING UNIT



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DEPARTMENT OF THE NAVY  
NAVY EXPERIMENTAL DIVING UNIT  
PANAMA CITY, FLORIDA 32407-5001

IN REPLY REFER TO:

NAVSEA TASK 86-45/87-11

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NEDU REPORT NO. 1-88	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THERMAL CONSIDERATIONS WHEN USING THE MK 16 Mod 0 UNDERWATER BREATHING APPARATUS IN 4.4°C (40°) WATER	5. TYPE OF REPORT & PERIOD COVERED FINAL	
	6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s) LCDR M.E. KNAFELC, MC, USN	8. CONTRACT OR GRANT NUMBER(s)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS NAVY EXPERIMENTAL DIVING UNIT PANAMA CITY, FL 32407-5001	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE FEBRUARY 1988	
	13. NUMBER OF PAGES	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this Report) UNCLASSIFIED	
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report)  DISTRIBUTION STATEMENT A: Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) NAVSEA TASK 87-11 NAVSEA TASK 86-45 NEDU TEST PLAN 87/28 MK 16 MOD 0 EOD DRY SUIT MK1 MOD 0 OXYGEN CONSUMPTION THERMAL		
20. ABSTRACT (continue on reverse side if necessary and identify by block number) To assure safe dive planning, the CO <sub>2</sub> absorbent canister duration limits, diver thermal protection, and decompression profile must be tested as an integrated package. The objective of this study was to evaluate the MK 16 Mod 0 closed circuit mixed gas SCUBA along with the equipment necessary to support a diver for the longest HVAL 21 Decompression Table in 4.4°C (40°F) water. The diver's core temperature and oxygen consumption along with the MK 16 canister effluent CO <sub>2</sub> were measured prior to the dive termination. All dives were aborted for thermal considerations. The first article EOD Dry Suit MK 1 Mod 0 is inadequate to support a diver in a long duration, cold water dive. The MK 16 is capable of supporting all the HVAL 21 Decompression Tables that require in-water decompression in temperatures 40°F and above. The polypropylene moisture absorbent pads are suitable replacements for the current foam pads and can be used until evidence of gross deterioration. (AW/Myne) ←		

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## ABSTRACT

To assure safe dive planning, the CO<sub>2</sub> absorbent canister duration limits, diver thermal protection, and decompression profile must be tested as an integrated package. The objective of this study was to evaluate the MK 16 Mod 0 closed circuit mixed gas SCUBA along with the equipment necessary to support a diver for the longest HVAL 21 Decompression Table in 4.4°C (40°F) water. The diver's core temperature and oxygen consumption along with the MK 16 canister effluent CO<sub>2</sub> were measured during the dive. All dives were aborted for thermal considerations. The first article EOD Dry Suit MK 1 Mod 0 is inadequate to support a diver in a long duration, cold water dive. The MK 16 is capable of supporting all the HVAL 21 Decompression Tables that require in-water decompression in temperatures 40°F and above. The polypropylene moisture absorbent pads are suitable replacements for the current foam pads and can be used until evidence of gross deterioration.

## KEY WORDS

NAVSEA TASK 87-11

NAVSEA TASK 86-45

NEDU TEST PLAN 87/28

MK 16 MOD 0

EOD DRY SUIT MK 1 MOD 0

OXYGEN CONSUMPTION

THERMAL

## INTRODUCTION

The MK 16 Mod 0 Underwater Breathing Apparatus (MK 16) is a closed circuit mixed gas SCUBA which maintains a constant  $ppO_2$  of 0.75 ATA. To assure safe dive planning, the MK 16 and its  $CO_2$  absorbent canister duration limits, diver thermal protection, and decompression profiles must be evaluated as an integrated package. The objective of this study was to evaluate the MK 16 along with the equipment necessary to support a diver on a 270 FSW dive for a bottom time of 25 minutes in  $4.4^\circ C$  ( $40^\circ F$ ). This is the longest HVAL 21 decompression dive profile which requires decompression. The areas of critical concern include the MK 16 canister performance, the EOD MK 1 Mod 0 dry suit, and the MK 16 polypropylene water absorbent pads.

The Navy Experimental Diving Unit (NEDU) policy to determine canister duration limits was based on working scenario with an average oxygen consumption rate of  $1.5 VO_2$  pm. This method insured that the diving apparatus would always provide a safe breathable gas to the diver. The MK 16 canister duration is 300 minutes according to this method, reference (1). However, the longest dive time on the HVAL 21 Decompression Tables is 331:30 minutes which consists of a 25 minute bottom time at 270 FSW and 306:30 minutes of decompression. Given that the diver is at rest for the majority of the dive it is assumed that the MK 16 is capable of supporting the diver on this profile provided the diver has adequate thermal protection, reference (1).

The critical concern is the diver's thermal protection. The possibility may exist that a diver may become so cold during the dive the oxygen consumption and hence  $CO_2$  production may exceed the capacity of the absorbent canister. With the development of long duration SCUBA the issue revolves around man's capabilities. In particular, will the diver's oxygen consumption rate increase beyond the levels of a working diver to maintain a minimum body core temperature of  $36^\circ C$  ( $96.8^\circ F$ )? If this occurs, the MK 16  $CO_2$  absorbent canister may not have a sufficient amount of scrubbing capability. A preliminary evaluation of the EOD dry suit suggested that this suit is capable of thermally protecting the diver in  $2^\circ C$  ( $35^\circ F$ ) for six hours (NEDU unpublished data). The present study was designed to measure the diver's oxygen consumption rate and thermal status for a simulated mission involving an in-water time of 331:30 minutes along with the MK 16 canister effluent  $CO_2$ .

The current MK 16 water absorbent pads quickly deteriorated after three or four uses, reference (1). A polypropylene pad was found to be a suitable replacement for use with the MK 15 Mod 0 (MK 15) closed circuit SCUBA, which is similar in design concept to the MK 16, reference (2). The use of this type of pad (form cut) for the MK 16 will be evaluated during this study for possible replacement of the MK 16 foam pads.

## METHODS

### Diver-Subjects

Five U. S. Navy Explosive Ordnance Disposal (EOD) divers participated in this dive series. All divers were familiar with the operation of the MK 16.

Age, height, and skinfold thickness over the biceps, triceps, subscapular and suprailiac crest were measured, Table 1. The divers were instructed to eat a substantial breakfast on their dive day and to refrain from alcohol at least 30 hours prior to their dive.

The diver dress consisted of the EOD dry suit, as issued to the EOD team which consisted of a neoprene outer garment with a detachable hood, double wet suit gloves, and Thinsulate® 200 underwear. Air was used as the suit inflation gas.

#### Dive Profile

All instrumented dives took place in the Ocean Simulation Facility (OSF) located at the Navy Experimental Diving Unit (NEDU), Panama City, FL. The water level in the wet chamber was 3 FSW as measured to the diver's chest. The water temperature was 4.4 to 5.6°C (40 to 42°F). The longest case HVAL 21 decompression profile, 270 FSW for 25 minutes, was attempted. Due to diver suit inflation problems the maximum depth was not achieved, but the schedule of 25 minutes of work, which includes the time to reach the bottom, followed by resting decompression was maintained. The divers rode a modified Collins Pedal-Mode ergometer (Braintree, MA) placed in a 37° head-up attitude to simulate work. The electric brake to the ergometer was turned off which on the surface has an internal resistance equal to 11 to 13 watts. This watt load in conjunction with the dry suit and fluid resistance results in 60 to 100 watts of actual underwater work (NEDU unpublished data). Two divers participated for each of the two dives.

In the event of a flooded glove the diver went to the trunk for a change. At any time the diver went to the trunk he gave an overall evaluation of his thermal state, i.e., pain, shivering, numb. The dive was aborted when the diver thermal status was in jeopardy either by his report or by his temperature readings.

#### MK 16 Preparation

Each UBA was set up at 1.0 ATA according to the MK 16 MOD 0 UBA OPERATIONS AND MAINTENANCE MANUAL (SS 600-AH-MMA-010, 1 May 1985). A freshly charged primary battery (Power-Sonic Model PS-610) and four new secondary batteries (1.5v carbon zinc) were used for each dive. The canisters were packed with High Performance (HP) Sodasorb (W. R. Grace., Atlanta, GA) of the same expiration date. The HeO<sub>2</sub> diluent gas used were mixtures that had an oxygen partial pressure of 0.75 ATA at the test depth. Thus, the diluent gas replaced any gas volume lost from the MK 16 due to mask clearing, gas sampling, etc. with the appropriate gas mixture. This method makes any gas lost from the UBA negligible and can be ignored when calculating oxygen



consumption, reference (3). The oxygen consumption was calculated using the following equation, reference (3).

$$\dot{VO}_2 = (WP/t) \cdot V_b \cdot [273/(T+273)]$$

$\dot{VO}_2$  = oxygen consumption (liters/min at STP)

WP = change in pressure (ATA)

t = time (minutes)

$V_b$  = floodable volume of  $O_2$  bottle (2.80 liters)

T = water temperature (°)

Each MK 16 moisture absorbent pad was made with Duon® polypropylene non-woven fabric (Phillips Fibers Corporation, Greenville, S.C.) that were form cut by Rexnord Breathing Systems (Malvern, PA). After surfacing the canister holder was inspected for free water and the pads examined for any gross deterioration. The pads were reused throughout the dive series including the work-up dives. All pads were soaked in Betadine, rinsed thoroughly with fresh water and air dried after each use as per current fleet procedures.

The MK 16 inhalation hose near the backpack was instrumented with a small diameter (.032 inch I. D.) nylon capillary sample line. The gas sample was analyzed by a mass spectrometer (Perkin Elmer MGA 1100 Pomona, CA) that was calibrated prior to the dive and had calibration checks every 30 minutes of the dive. A pressure transducer (Druck PTX 160/D 0-5000 psig Newfairfield, CT) replaced the high pressure oxygen gauge and was calibrated prior to each dive. This allowed monitoring of the diver's gas mixture and oxygen bottle pressure which were recorded every 10 minutes.

## RESULTS

The test pool training phase of this dive series revealed a number of problems with the EOD Dry Suit as issued. In order to accomplish the dives alternate dry suits and undergarment combinations were tried.

Specific concerns about the EOD Dry Suit were raised by the divers and the principle investigator. They included the following:

One of the new EOD dry suit buoyancy control valves failed flooding the suit early in the dive, furthermore, this valve also was easily unscrewed off the suit by the diver while in the water trying to adjust his buoyancy; boots are too small to accommodate the diver's feet and thermal insulation; the suit pony bottle is strapped onto the thigh and can rapidly become dislodged interfering with the diver's movement; the air bottle manifold is too large and becomes easily fouled; the air whip is too long and does not positively lock onto the suit; the air bottle valve is too small to permit ease of use;

air delivery into the suit is slow necessitating the diver to ride the air inflation valve during descent; there is insufficient air supply for suit inflation to depth; the full face seal provides only a slit for the diver's mouth making it impossible to insert a mouthpiece by himself; the hood is too small to wear any thermal protection on the head and neck; the EOD face mask was too rigid and quickly lost its seal in cold water; and weight belts cannot be worn comfortably with the MK 16 and are particularly cumbersome when used with a dry suit.

Due to the inadequate thermal protection afforded by all the suit combinations, the divers were not able to accomplish a 331:30 total dive time. One diver had an in-water time of 277 minutes, the other three dive times were approximately 210 minutes. At no time did the canister effluent CO<sub>2</sub> exceed 0.00% SEV.

After multiple uses of the polypropylene moisture absorbent pads, at least nine dives per set, there was no evidence of deterioration. The divers noted no degradation of the MK 16 breathing performance.

The mean oxygen consumption rate obtained by a cold resting diver was 0.83 alpm. Table 2 lists the oxygen consumption rates for all the divers prior to exiting the water. In each case the diver felt he could not continue the dive because of the cold.

## DISCUSSION

Though the maximum depth of 270 FSW was not achieved this would not have affected the performance of the MK 16. Previous unmanned canister duration studies have shown that the MK 16 is insensitive to excursions to 300 FSW in temperatures of 40°F and above, reference (1). When overlaying the graphs of the CO<sub>2</sub> levels obtained on this dive series with those of previous dives it can be extrapolated that the MK 16 is capable of supporting a diver for all the HVAL 21 decompression profiles in water temperatures 40°F and greater. The oxygen consumption rates achieved by the cold divers prior to terminating the dive did not reach the levels obtained by a working diver.

The limiting factor to accomplish dives to the limit line of the HVAL 21 Decompression Tables in 40°F is the diver thermal protection. The first issue EOD dry suit used only 200 Thinsulate®, a wet hood, and a double layering of wet suit gloves. During the training phase for the dry suit, conducted in the test pool at NEDU with a water temperature of 40°F, the divers aborted the dive after 30 minutes due to painful hands and feeling extremely cold.

After diving the EOD dry suit in the test pool, the divers were given a suit preference since the dive series could only be safely accomplished if the diver is reasonably comfortable. The suits dove in the series were the EOD dry suit with 600 Thinsulate®, the TLS (Diving Unlimited International, San Diego, CA) suit with DMC P/N R27 undergarment (Port Charlotte, FL) or the Viking Pro® suit (Stratford, CT) with Thinsulate® 600 or DMC underwear. In addition, it was necessary to incorporate the Viking® three finger dry suit

glove system into all the dry suits since it was the only system available that would provide the most thermal protection for the hands. However, the overglove was too small to accommodate sufficient thermal insulation.

None of the suits had a sufficient air supply to prevent a suit squeeze to depths of 270 FSW. This resulted in limiting the maximum depth of the dive to the depth where the diver had adequate suit inflation. The depths achieved for the two dives were 225 and 80 FSW. The 80 FSW dive initially went to a depth of 200 FSW but had to ascend to 80 FSW because of a suit squeeze. There was an insufficient air supply due to a slow leak from the suit inflation manifold. To minimize a hand squeeze a six inch plastic tube, 1/4 inch I.D., was placed under the wrist seal. However, upon ascent one diver did experience his glove blowing off. For thermal protection it is necessary to have a layer of air in and around the insulating material; thus, dry gloves must be positively locked on to the sleeve of the dry suit to prevent such an occurrence during an operational dive.

All the dives were aborted because of the cold. The most common complaint was painful hands or feet which were numb and nonfunctional after 90 minutes into the dive. The dives continued after rewarming the hands. When the core temperature dropped to 36°C (96.8°F) the dive was terminated, because any further drop would result in impairment of the diver's judgment and performance. One diver had a dive time of approximately 277 minutes in the water. On interviewing him after the dive, he stated he was experienced in cold water diving and ignored the pain he experienced. However, his hands were useless and he had reached the maximum of his endurance for this temperature and suit configuration.

#### CONCLUSIONS

The MK 16 Mod 0 is capable of supporting all dives using the HVAL 21 0.7 ATA Oxygen Fixed ppO<sub>2</sub> in Helium Decompression Tables in temperatures 40°F and greater.

The polypropylene moisture absorbent pads are adequate replacements for the current foam pads. In addition, they can be reused using the current disinfectant methods until there is evidence of gross deterioration.

The first issue EOD dry suit is totally inadequate in providing thermal protection in 40°F water. None of the suit combinations used during this series are able to support a resting diver for 5 hours in 4.4°C (40°F) water.

TABLE 1  
Diver-Subject Physical Characteristics

Number	Age (yr)	Height (cm)	Biceps (Skinfold thickness - mm)	Triceps	Suprailiac	Subscapular
1	24	183	6.0	10.3	21.6	11.6
2	34	175	11.6	8.0	23.0	13.6
3	39	180	6.0	9.0	25.0	15.5
4	31	183	5.0	7.0	23.6	17.0
5	29	180	3.6	6.6	16.0	16.6

**TABLE 2**  
**Oxygen Consumption Rates for Cold Resting Divers**

Diver No.	In-water Time (min)	VO <sub>2</sub> (slpm)	Core Temp. (°C)	Comment
1	209	1.20	36.98	Painful feet
3	277	.53	36.19	Shivering
4	211	.87	37.83	Cold, abort
5	<u>226</u>	<u>.71</u>	38.20	Shivering, abort
	231±32	.83±.28		

Diver No. 2 only participated in the test pool phase of this dive series.

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